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(54) Title: HEAT SINK			
(57) Abstract			
<p>A heat sink (11) for transferring heat away from an object (35). The heat sink (11) is composed of a flexible binder and a plurality of thermally conductive particles dispersed in the binder for transferring heat from the object (35) through the binder.</p>			

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HEAT SINK

Cross Reference to Related Applications

This application is a continuation-in-part of U.S. Serial No. 08/208,809 filed March 10, 1994, which is a continuation of U.S. Serial No. 07/988,217 filed December 9, 1992, now abandoned. The disclosures of the above-mentioned applications are incorporated herein by reference.

Government Rights

The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms of Contract No. ITA 87-02.-

Brief Description of the Invention

This invention relates generally to a heat sink and method of fabrication, and more particularly to an injection-molded thermally conductive heat sink and method of fabrication.

15

Background of the Invention

Excessive heat developed during operation of integrated circuits, particularly very large integrated circuits such as microprocessors, controllers and other high performance electronic logic devices can drastically reduce the reliability and efficiency of the circuit. The increased electronic packaging and power densities of many high performance devices often result in a high heat concentration within a limited area. Dissipation of the excessive heat is critical to prevent damage to or failure of the device. However, the high packaging density of the devices places many constraints on the design of a suitable thermal management system. Finding adequate methods to remove the excess heat has become a very important design parameter in building high performance electronic circuitry.

Many different approaches have been taken to disperse the excess heat that is generated in electronic circuits. One of the most common ways to dissipate the heat is through the use of heat sinks fabricated from extruded aluminum, but aluminum heat sinks have certain physical design limits. One limitation is the shape, which is limited to simple two-dimensional profile shapes that can be extruded. This reduces the potential for developing heat sinks having a reduced size or complex shapes which increase the convective and radiant cooling efficiency of the heat sink.

Another limitation is the rigidity of the heat sink which prevents the heat sink from conforming to the shape of the electrical components, printed circuit board and the like. Gaps or spaces may be introduced between the contacting surfaces of the components or printed circuit board and the attached heat sinks because of normal manufacturing tolerances, substantially inhibiting heat transfer between the surfaces. If the heat sink is attached to two or more components, the thermal efficiency of the heat sink may be greatly reduced as the gaps and spaces between contacting surfaces become more abundant. Flexible thermal pads or epoxies have been applied between the contacting surfaces to eliminate air spaces and improve heat transfer between the electronic component and the heat sink. However, the use of such pads or epoxies often introduces potentially damaging thermal stresses between the components and the heat sink as the heat sink, thermal pad or epoxy and electronic component have different coefficients of thermal expansion.

A new type of heat sink is constructed of filled polymer material that can be injection-molded into a variety of compact, complex shapes which are highly efficient for convective cooling with high velocity forced air. Although the filled polymer material has only about two percent of the thermal conductivity of pure aluminum, these complex-shaped devices have a cooling capacity that is comparable to bulky aluminum heat sinks that cannot fit in a compact, forced convection environment. Because of the materials and processes used to fabricate the heat sinks, the filled polymer heat sinks are also substantially rigid.

To install aluminum or polymer heat sinks, they must be mounted to the device that is to be cooled. This bond is usually accomplished by using mechanical fasteners, compressible pads, silicone grease or conductive epoxies. A major thermal management problem with bonding of these existing heat sinks is a reduction in thermal conductivity

across the bond. Also any voids or gaps between the two joint surfaces can easily go undetected and can greatly reduce the thermal efficiency of the joint area.

Other heat sink approaches use liquid-filled pouches or copper-covered sponges compressed between the printed circuit board components and the outside casing of the instrument to transport the heat away from the heat source. These heat sinks offer some flexibility, allowing the heat sink to be used with several electrical components. The efficiency of the copper covered sponges is limited as heat is transferred only by the copper exterior. Moreover, these heat sinks greatly restrict the airflow through and around the printed circuit board and related chips. As a result, they appear to be limited to only special applications.

Summary of the Invention

Accordingly, it is a general object of this invention to provide a new type of heat sink capable of dissipating the increasing heat loads of advanced integrated circuitry with improved efficiency and versatility.

It is another object of the invention to provide an improved injection-molded heat sink and method of fabrication.

It is a further object of the invention to provide a flexible injection-molded metal heat sink employing high conductivity powders fabricated in complex shapes and a method of manufacture.

It is a further object of the invention to provide heat sinks molded from a flexible binder loaded with highly conductive powders.

It is a further object of the invention to provide an injection-molded heat sink that can be attached to several different sized components.

These and other objects of this invention are achieved by a heat sink for transferring heat away from an object. The heat sink is molded in selected shape and comprises a flexible binder, such as a thermoplastic elastomer, and a plurality of thermally conductive particles mixed with the binder for transferring heat through the binder. The proportion of thermally conductive particles in the mixture is between twenty and eighty percent by volume.

Brief Description of the Drawings

The purpose and advantages of this invention will be apparent to those skilled in the art from the following detailed description in conjunction with the appended drawings, wherein:

5 Figure 1 is a perspective view schematically showing a heat sink including four posts.

Figure 2 is a schematic view of a heat sink with four configured posts.

Figure 3 is an end view of another heat sink.

Figure 4 is a schematic flow chart showing the fabrication of a heat sink in
10 accordance with the invention.

Figure 5 is a schematic end view showing the heat sink mounted to a plurality of electronic components on a printed circuit board.

Figure 6 is a schematic top plan view of another heat sink.

Figure 7 is a schematic end view of the heat sink of Figure 6 showing the two
15 heat sources and a plurality of thermocouples applied to the heat sink.

Description of Preferred Embodiment

Generally, in accordance with this invention, highly conductive particles are mixed with a flexible binder and the mixture is molded into the shape of the desired heat sink. The flexible heat sink is suitable for many applications, and may be used to
20 cool one or several components of a device. The method of the invention can be used to economically produce heat sinks of desired flexibility and thermal conductivity levels by appropriate selections of the conductive material and the binder material, the particle size of the conductive material, and the volume loading of the powder particles in the binder.

25 Figure 1 schematically shows a heat sink 11 having a base 12 and integral outwardly projecting posts 13. This shape can be easily molded in accordance with this invention. It should, of course, be understood that this representation is only schematic and that posts having any desired configuration can be easily molded by the process of the invention. In Figure 2, the heat sink 11 includes posts 14 which have a corrugated
30 or shaped configuration to increase the surface area for heat transfer by radiation and conduction to the surrounding area. As shown in Figure 3, the thickness of the base

12 and the height of the posts 13 need not be uniform throughout the heat sink 11. Instead, the shape of the heat sink may be tailored to the specifications of a particular application.

The heat sink 11 is manufactured in accordance with the present invention by molding a mixture of a highly conductive powder and a flexible binder. The highly conductive powder is preferably a metal having a low thermal resistance. The metal powder may be produced using inert gas, air or water atomization processes using annular-slit nozzles, close-coupled nozzles or conventional free-fall nozzles; or the metal powder may be made by other processes such as electrolytic, grinding, chemical fiber processing, etc., that yield powders having the appropriate size for use in the fabrication of heat sinks. Copper, boron nitride, silver, aluminum, molybdenum, aluminum nitride, silicon carbide, silica, carbon, diamond powders and alloys of these materials are suitable for use. The particles are selected with a size distribution in the range of 0.1 to 5000 microns with the preferred range being 25 to 50 microns.

The thermal conductivity of the heat sink will depend primarily on the thermal conductivity of the powder. The preferred material chosen for this application is copper. Copper has extremely high thermal and electrical conductivity and is available economically in high purity ingots or bar stock. Preferably, the copper powder is formed of a melt of electronic grade copper (99.99% pure) atomized by a high pressure inert gas atomization process (HPGA) of the type described by Ayers and Anderson in U.S. Patent 4,619,845, the teaching of which is incorporated herein by reference. The electrical conductivity of HPGA copper powder pressed to full density was essentially equal to that of electronic grade copper, having a thermal conductivity of 226 BTU/ft/hr/degree F at 68°F. For comparison, the thermal conductivity of heat sinks comprising a polymer filled with aluminum is 3.1 BTU/ft/hr/degree F at 68°F, and the thermal conductivity of commercial purity aluminum alloy used for heat sinks is approximately 128 BTU/ft/hr/degree F at 68°F. Although the commercial purity copper powder has a slightly reduced electrical conductivity relative to the HPGA copper, the conductivity of the commercial copper powder is far superior to aluminum powder.

The binder material is preferably a thermoplastic elastomer. The flexibility of the heat sink 11 depends upon the stiffness of the binder material. Preferably, the

binder material has a hardness in the range of Shore A10 to Shore D90 to provide the heat sink with sufficient flexibility. Suitable thermoplastic elastomers include thermoplastic olefins, olefinic thermoplastic vulcanizate, styrene block copolymer, thermoplastic urethane copolyester, copolyamide and santoprene. Since these thermoplastic elastomers are available in a several stiffness values, the flexibility of the heat sink may be tailored to meet the requirements of a particular application. The binders may include a coupling agent such as glycerol, titanate, stearic acid, polyethylene glycol, humic acid, ethoxylated fatty acids and other known coupling agents to achieve higher loading of the powder particles in the binder.

Referring to Figure 4, the powder particles 16 are either screen-classified or air-classified so that they fall within the desired range of particle size. The powder particles 16 and pellets of a thermoplastic elastomer binder 17 including a solvent 18 and a lubricant 19, if desired, are heated and mixed into a compound which is then heated and molded to the desired shape. Coloring agents 20 may also be added to the mixture to increase the emissivity of the heat sink 11 or to color the heat sink to provide for example a visual indication of the thermal conductivity or the identify of the manufacturer of the heat sink. The binder and alloy powder are mixed in proportions selected to provide the desired thermal conductivity and flexibility for the heat sink. The thermal conductivity is dependent upon the amount of powder in the mixture or volume loading of powder in the binder, with a high volume loading of powder offering increased thermal conductivity. Blends of 20 to 80 volume percent copper have been found to be highly satisfactory. High volume loading of powder, for example 70-80%, may be achieved by using the fine spherical particles produced by HPGA process. Blends of different particle sizes can also be used to achieve optimum volume loading, whereby the smaller particles can fit in the interstices between the larger particles to provide a higher volume filling.

The powder particles 16 and binder 17 are preferably mixed as shown in Fig. 4, although it should be understood that other processes may be used to mix the binder and powder particles into a compound. As shown in Fig. 4, the powder particles 16, binder pellets 17 and any additives are mixed in the mixer 21 and then fed into a twin-screw extruder 22 which further mixes and extrudes the mixture. The extruder preferably heats the powder particles 16 and elastomer pellets 17 and uses moderate to high

shear mixing to provide a homogeneous feedstock. The extruder may include a plurality of heating zones in the range of 150° to 200°C, with the highest temperature located at the extrusion end. For example, the extruder may have four zones set at 150°C, 170°C, 190°C and 200°C. After the material is extruded, it is cooled and supplied to
5 the granulator 23 where it is ground into compound pellets 24. To ensure complete mixing, the process of mixing-extrusion-granulation may be repeated several times.

After the compound has been completely mixed, the ground compound pellets 24 are then heated and molded to the desired shape. Instead of adding the coloring agents 20 when the binder and powder particles are initially mixed in the mixer 21, the
10 coloring agents may be added to the compound pellets 24 when heated. The heat sink 11 may be formed by injection molding, extrusion, rotation molding, pressure molding, compression molding, etc. In the process shown in Fig. 4, for example, the compound pellets 24 are supplied to a reciprocating screw injection molder 26. The injector 26 may also have a plurality of heating zones, where the temperature at the injection end
15 27 of the injector is 200°C. The heated mixture is injected into a molding cavity 28. The cavity is then opened, and the shaped heat sink 11 is allowed to cool.

As previously described, the conductivity of the heat sink is dependent upon the particle volume loading, particle conductivity and polymer conductivity. The thermal conductivity increases as the volume fraction of powder particles increases. Spherical
20 powder particles are more easily molded than irregular particles at the higher volume fractions of loading; however, this does not preclude the use of irregular particles such as carbon fibers in molding applications. Non-spherical particles with a rough surface have a lower packing density and coordination number than spherical particles due to both physical constraints and particle interaction. The increased surface roughness
25 results in interlocking of particles and greater difficulty for particles trying to slide past one another. For example, molding of the irregular copper powder with binder was difficult because of the loss of fluidity, whereas the mixture of binder with the fine spherical copper powder was still very fluid at 60 volume percent.

As shown in Fig.5, the flexible heat sink 11 may be used to cool several different
30 components 35 on a printed circuit board 36. The flexible heat sink 11 conforms to the shape of the components 35, accommodating variations in manufacturing tolerances and eliminating the need for thermal pads, epoxies and the like between the heat sink and

the components. The heat sink 11 may be mounted directly to the components 35 by adhesive or other known mounting means. Because the heat sink 11 is flexible, the heat sink may be compressed against the components 35 to ensure that the entire surface of the component 35 contacts the heat sink 11. Instead of being mounted to the components 35, the heat sink may also be secured to the printed circuit board 36 in contact with the components 35 as is known in the art. A portion of the heat sink may also conform to and be positioned in contact with the external housing of the electronic package for transferring heat away from the components 35 by conduction as well as convection. When the heat sink 11 is in contact with the external housing, the flexibility of the heat sink also reduces the effects of vibrations and force of impact on the components 35 and the printed circuit board 36.

With the powder particles 16, the thermal conductivity of the heat sink 11 is equal to or greater than the combination of a thermal pad and metal heat sink. Thermal stresses induced by the thermal expansion of the components are also substantially reduced as the heat sink may be compressed by the expanding component. Thus, the performance of the heat sink 11 is not affected by the heat sink and electronic components 35 having different coefficients of thermal expansion.

Example 1

In one example, particles of HPGA copper powder having a size in the range of 45 to 106 micrometers were blended with a binder of Advanced Elastomer Systems santoprene 80. The mixture included 896 grams of HPGA copper powder and 97 grams of the santoprene binder, providing a volume percent loading of 52% volume copper to 48% volume binder. The copper and binder particles were mixed in twin screw extruder having four zones set at 180°C, 180°C, 190°C and 200°C, respectively. The extruded compound was ground into pellets approximately 1/4 inch long. The copper/binder pellets were fed into an injection molder having four zones set at 180°C, 200°C, 210°C and 210°C and molded into a heat sink 11 having the shape shown in Figure 6.

Example 2

In a second example, a powder particle/binder mixture consisting of PK120 Carbon Fiber particles (AMOCO) and the Advanced Elastomer Systems santoprene 80 was prepared. The mixture included 200.0 grams of carbon particles and 108.8 grams of the santoprene binder to obtain a mixture having 45% volume carbon and 55%

volume santoprene. The particles and the binder were mixed and compounded in a twin screw extruder having four zones set at 180°C, 180°C, 190°C and 200°C, respectively, and the compound was ground into 1/4 inch pellets. An injection molder with four zones set at 180°C, 200°C, 210°C and 210°C was used to melt the pellets and
 5 mold the mixture into a heat sink 11 having the shape schematically shown in Fig 6.

The copper/santoprene heat sink of Example 1 and the carbon/santoprene heat sink of Example 2 were positioned in contact with a heat source to demonstrate the heat transfer properties of the heat sinks. As shown in Figure 7, the heat sink 11 is positioned with the smaller end 39 above a first resistor 40 operating at 3 watts and the
 10 larger end 41 above a second resistor 42 operating at 13 watts. During the testing period, the ambient air temperature was 45°C and the air flow over the heat sink measured 200 ft/min. A plurality of thermocouples TC1-TC8 were used to measure the temperature of the heat sink 11 at several different positions. The measured temperatures for the copper/santoprene heat sink and the carbon/santoprene heat sink
 15 are provided in the following table:

TABLE: Heat Sink Temperatures (°C)

	Thermocouple	Copper/Santoprene Heat Sink	Carbon Santoprene Heat Sink
20	TC1	107.0	96.67
	TC2	59.8	58.52
	TC3	56.2	56.8
	TC4	52.5	54.07
	TC5	48.0	48.47
	TC6	52.1	50.54
25	TC7	56.9	56.0
	TC8	54.2	54.4

Thus, there has been provided a flexible heat sink which can be molded into desired shapes from a highly thermal conductive material comprising metal particles dispersed in a thermoplastic elastomer binder. The flexible heat sink maximizes surface
 30 contact between the heat sink and electronic components and minimizes the adverse effects of any differences in the thermal coefficients of expansion of the heat sink and the component. The efficiency of a thermal management system incorporating the flexible heat sink of the present invention is thereby increased.

WHAT IS CLAIMED:

1. A heat sink for transferring heat away from an object comprising:
a heat sink body formed of a flexible binder, said body having a base and extended surface means of selected shape projecting from said base to define an extended heat exchange area for transferring heat away from said heat sink body by convection or radiation, and
a plurality of thermally conductive particles dispersed in said binder for transferring heat through said binder.
2. The heat sink of Claim 1 in which said binder is a thermoplastic elastomer.
3. The heat sink of Claim 2 in which said thermoplastic elastomer is one selected from the group comprising thermoplastic olefins, olefinic thermoplastic vulcanizate, styrene block copolymer, thermoplastic urethane copolyester, copolyamide and santoprene.
4. The heat sink of Claim 1 in which said binder has a hardness in the range of Shore A10 to Shore D90.
5. The heat sink of Claim 1 in which said heat sink body is molded to a shape selected for simultaneously transferring heat away from a plurality of objects to said extended heat exchange area.
6. The heat sink of Claim 1 in which said thermally conductive particles are formed of at least one material selected from the group comprising copper, silver, diamond, aluminum, molybdenum, aluminum nitride, silicon carbide, boron nitride, quartz, and carbon.
7. The heat sink of Claim 1 in which said thermally conductive particles have a size in the range of 0.1 to 200 microns.

8. The heat sink of Claim 1 which further includes at least one coloring agent dispersed in said binder for increasing the emissivity of said heat sink.
9. A heat sink for transferring heat away from an object comprising
 - a flexible heat sink body formed of a thermoplastic elastomer binder, said body having a base positionable on a heat source and extended surface means of selected shape projecting from said base to define an extended heat exchange area for transporting heat away from said heat sink body by convection or radiation, and
 - a plurality of thermally conductive particles mixed with said binder for transferring heat through said binder, the proportion of said thermally conductive particles in said mixture being between twenty and eighty percent by volume.
10. The heat sink of Claim 9 in which said thermoplastic elastomer is one selected from the group comprising thermoplastic olefins, olefinic thermoplastic vulcanizate, styrene block copolymer, thermoplastic urethane copolyester, copolyamide and santoprene.
11. The heat sink of Claim 9 in which said binder has a stiffness value in the range of Shore A10 to Shore D90.
12. The heat sink of Claim 9 in which said heat sink body is molded to a shape selected for simultaneously transferring heat away from a plurality of dissimilar objects to said extended surface means.

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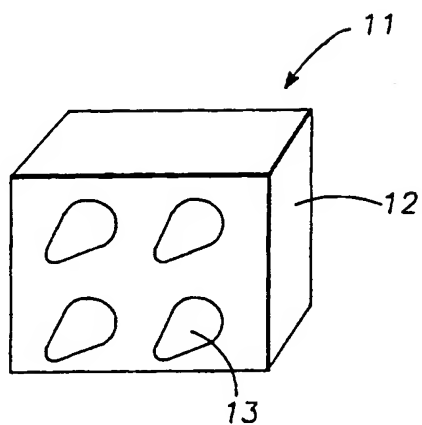


FIG. -1

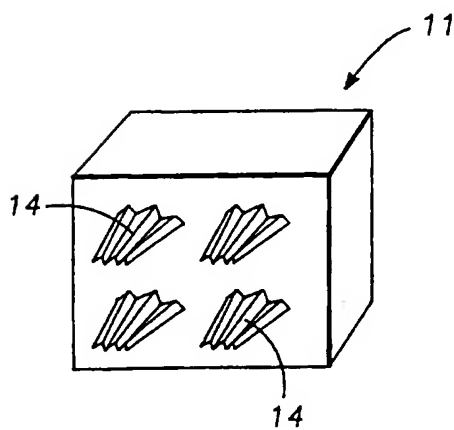


FIG. -2

2 / 4

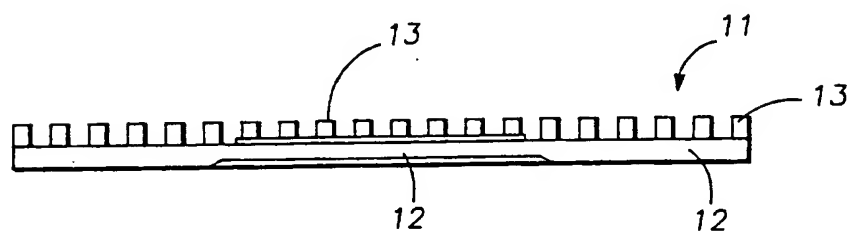


FIG. -3

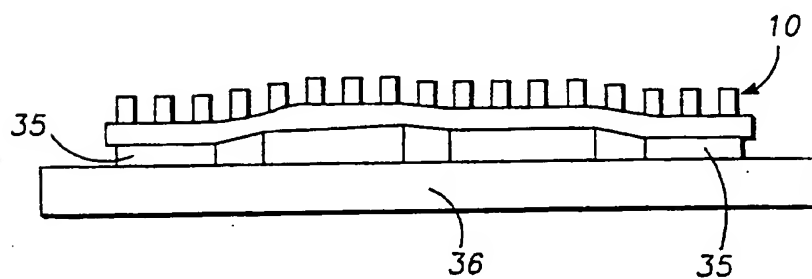


FIG. -5

3 / 4

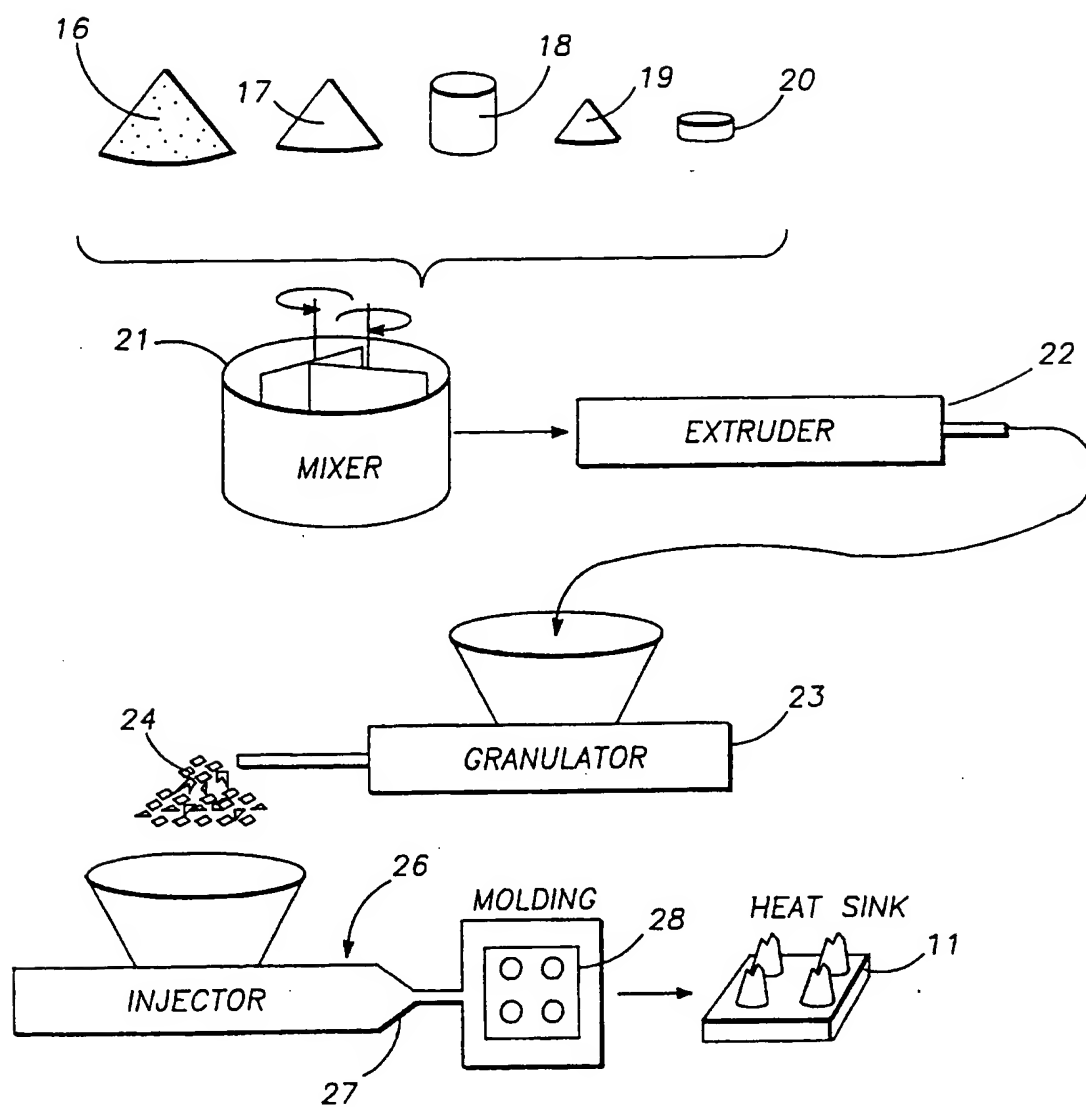


FIG.-4

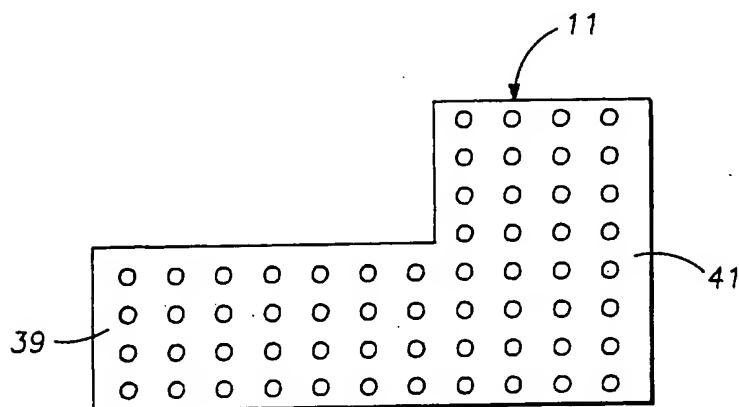


FIG. -6

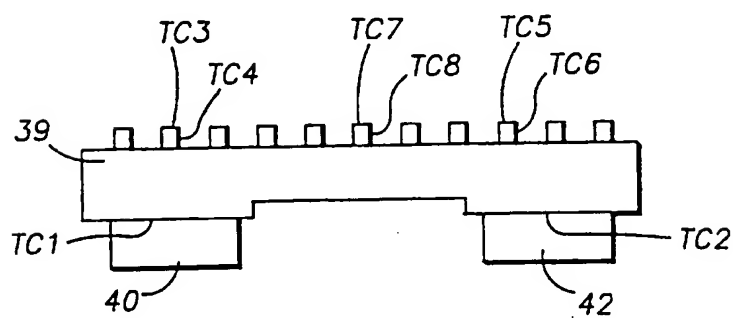


FIG. -7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US95/10511

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : F28F 7/00; H05K 7/20

US CL : 165/80.3, 185; 174/16.3; 257/720, 722; 361/704, 707

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 165/80.3, 185; 174/16.3; 257/720, 722; 361/704, 707, 709

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 3,564,109 (RUECHARDT) 16 FEBRUARY 1971, see entire document.	1-12
X	DE, A, 2,511,010 (ZOBL) 23 SEPTEMBER 1976, see entire document.	1-12
Y	US, A, 4,869,954 (SQUITIERI) 26 SEPTEMBER 1989, see entire document.	1-12
A	US, A, 3,694,182 (AKFIRAT ET AL) 26 SEPTEMBER 1972, see All Figures.	1-12
A	US, A, 4,654,754 (DASZKOWSKI) 31 MARCH 1987, see Abstract.	1-12
A	US, A, 4,838,347 (DENTINI ET AL) 13 JUNE 1989, see Abstract.	1-12

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

* Special categories of cited documents:	*I* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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Date of the actual completion of the international search

27 OCTOBER 1995

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INTERNATIONAL SEARCH REPORT

International application No.
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5,285,108 (HASTINGS ET AL) 08 FEBRUARY 1994, see Figures 4-7, column 4, lines 2-10.	1-12